Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at http://about.jstor.org/participate-jstor/individuals/early-journal-content.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

THE

JOURNAL OF GEOLOGY

MAY-JUNE, 1902

THE DEVELOPMENT OF SYSTEMATIC PETROGRAPHY IN THE NINETEENTH CENTURY.[1]

CONTENTS.

Part I.—INTRODUCTION.

VIEWS OF ROCKS BEFORE THE NINETEENTH CENTURY.

Linnæus; Development of mineralogy; Foundations of petrography; Werner's classification of rock formations.

DEVELOPMENT OF SYSTEMS IN THE NINETEENTH CENTURY.

Abbé R. J. Haüy, 1801; John Pinkerton, 1811; Alexandre Brongniart, 1813; P. L. A. Cordier, 1815; John Macculloch, 1822; Karl Cæsar von Leonhard 1823; Alexandre Brongniart, 1827; Systems of von Leonhard and Brongniart compared.

Investigations into the Chemical Composition of Rocks; Classification by Feldspars; Influence of genetic hypotheses; Geological classifications.

Carl Friedrich Naumann, 1850, 1858; Bernhard von Cotta, 1855, 1862; Ferdinand Senft, 1857; J. Reinhard Blum, 1860; Justus Roth, 1861; Th. Scheerer, 1864; Ferdinand Zirkel, 1866; Ferdinand von Richthofen, 1868.

Cordier's System and its Influence; H. Coquand, 1858; Archibald Geikie, 1872,

---

Part II.—Beginning of the Microscopical Era; Ferdinand Zirkel, 1873; A. von Lasaulx, 1875; H. Rosenbusch, 1877; Foqué and Michel Lévy, 1879.

---

[1] An abstract of this review was delivered as a retiring presidential address before the Geological Society of Washington, December, 1900.

Samuel Allport; Clarence King, 1878; M. E. Wadsworth, 1884.

J. D. Dana, 1878; Karl A. Lossen; H. Rosenbusch, 1887; H. Rosenbusch, 1896.

Justus Roth, 1883; E. Kalkowsky, 1886; J. J. Harris Teall, 1886–1888.

Franz Schröckenstein, 1886, 1897; H. O. Lang, 1891; F. Loewinson-Lessing, 1890, 1897; A. Osann, 1900, 1901.

Ferdinand Zirkel, 1893–1894; H. Rosenbusch, 1898; Johannes Walther, 1897.

SUMMARY.

Part I.

INTRODUCTION.

THE systematic and descriptive science of rocks — petrography — is a product of the nineteenth century. One hundred years ago the distinction had not yet been drawn between the rock and the geological formation or terrane, and many dense rocks were still included among minerals and described as such. With the discrimination between stratigraphic units and rocks proper the science of petrography became outlined, but did not at first receive a name. For some time after the proper scope of the science was clearly defined its development was rapid, and in certain later periods there have been notable advances, due to the invention of some new method of research or to the stimulation afforded by discoveries in some closely allied branch of science.

For the last thirty years or more research in all directions has added greatly to our knowledge of rocks, through the adaptation of the microscope to their study, improved methods of chemical analysis, and a vast store of accurate field observations of occurrence and relationships. But the systematic part of the science has not kept even pace, and does not adequately express the knowledge of the day. This lagging behind on the part of the classificatory branch of petrography is most natural, and similar conditions have existed in various epochs of the past. It is due partly to the necessity for a thorough consideration of the store of new information concerning rocks before its true bearing upon classification could be correctly appreciated, and partly to prevailing differences of opinion as to the relations of petrography to the broader science of rocks — petrology.[1]

At the present time students in many parts of the world, dissatisfied with existing petrographic systems, are turning their attention to classification, and are attempting to apply the newly acquired knowledge, with or without the aid of theoretical considerations, to the construction of improved systematic arrangements of rocks. In view of this situation it has seemed appropriate to present at this time a review of the development of systematic petrography. An understanding of the steps taken in bringing the science to its present condition must certainly be useful to those who would assist in causing important advances in the future.

In this review no attempt will be made to give a complete historical sketch of petrography, but rather to study in a somewhat critical way the course of development through which the science has passed, to analyze the more important contributions to its advancement, and especially to examine the principles nominally applied in formulating schemes of classification and to test the methods of application as to their logical directness and consistency. From some cause the existing systems are commonly regarded as unsatisfactory and inadequate, and this condition indicates either that the principles of classification have not been wisely chosen or that they have been incorrectly applied.

That the standpoint of the reviewer may be clear, it may be well to state the principles which have guided him in his analysis of systematic propositions :

---

[1] The terms "petrology" and "petrography" have been so widely used in various senses that the writer wishes to urge an agreement among students of rocks to apply each in future in accordance with the scope implied in its etymology. On this basis the broad science or treatise of rocks is manifestly *petrology*, and the descriptive, systematic science, leading to the nomenclature of these objects, should be *petrography*. This usage corresponds to the definitions given in the "Lexique Pétrographique" prepared by F. Loewinson-Lessing, with the co-operation of many other petrographers, published in the *Compte Rendu of the Eighth International Congress of Geologists* (Paris).

1. A systematic classification of rocks has for its object the arrangement of all rocks in groups according to a method, producing a regular subordination of parts. While in all classifications the groups must possess certain chosen characters in common, the system is natural or artificial according as the groups express community of fundamental, important characteristics, or of comparatively unimportant properties, chosen for convenience only.

It is commonly admitted that rocks are incapable of truly natural classification, but that the nearest possible approach to a natural system is to be desired. It is, therefore, important to scrutinize systematic propositions to see if their factors of classification have a fundamental connection, making the sequence of divisions natural in desirable degree. Each factor applied should have important natural relations to those preceding and following it in construction of the system. The writer thus believes that the classification of systematic petrography should be a *hierarchical classification*, in distinction to the *cross-classification* necessary in petrology.

2. A systematic classification must be logical in construction. Whatever principles or criteria the architect of a system may adopt, he must be logically consequent and consistent in their application, else his structure is weak, and must fall.

3. It is unscientific to use an assumption which is known to be untrue as a basis of classification.

4. An adequate system of petrography must be stable and comprehensive. In order to fulfil these requirements it must be based upon knowledge, not upon theory or hypothesis ; it must be created for *all rocks*, known or unknown, of the characters now understood ; its framework must be capable of change in detail without injury to the structure as a whole.

5. The use of ignorance concerning the constitution of some rocks as a factor for their classification is no longer permissible.

If, in the comments to be made upon various systems, it appears to the reader that those of the present day are more severely criticised by the writer than those of earlier periods, it must be remembered that such a discrimination is natural and just. With greater knowledge of rocks, and with the experience of earlier systematists to guide him, the petrographer of the present day should be able to present a classification freer from defects than any proposed by his predecessors. It is the writer's aim to avoid all personal animus in discussion of the existing systems of classification.

Petrography may be concisely defined as the systematic classification of rocks. But if the principal handbooks of today be referred to, it will be found that it is a matter of supposed mutual understanding, rather than of precise statement, as to what constitutes a rock. It is commonly said that rocks are masses of geological importance in the constitution of the earth, but no very serious attempt is made to define what is of importance, or to discuss what treatment shall be given to substances excluded under such a definition. For the purposes of this review, it will be sufficient to define rocks as the *substances constituting* masses of geological importance, recognizing that geological units of mass are not necessarily units in constitution, and may change in material character from place to place. It is the task of petrography to furnish a systematic arrangement of these natural objects and a corresponding nomenclature. The geologist may wish to consider rocks from many different standpoints, each requiring a more or less special grouping and appropriate terms to express the observed or assumed relationships, and such groupings may be apart from systematic petrography.

VIEWS OF ROCKS BEFORE THE NINETEENTH CENTURY.

The category of rocks as understood today is somewhat different from the categories conceived to be the subject-matter of petrography in various epochs of the past. The early history of petrography is therefore in large degree a history of the differentiation of the sciences dealing with various categories of the mineral kingdom — mineralogy, stratigraphic geology, and petrography. But while a complete review of the subject must note the origin and application of the ideas by which this differentiation was brought about, it is more particularly the object of this retrospect to trace the development of classification, beginning with the time when it was first sought to distinguish a group of objects even approximately corresponding to rocks as at present understood. A brief consideration of the earlier stages is, however, necessary to a clear understanding of the conditions existing in the first decade of this century.

Linnæus.— Certain gems and ornamental stones were known to the ancients by names which they bear to this day; but no attempted classification of the mineral kingdom prior to the time of Linnæus, in the middle of the eighteenth century, need be considered at this time, nor is the system of Linnæus of much importance except for the framework of the classification he proposed for the mineral kingdom, the same which he applied with so much greater success to the organic world. It has been said of Linnæus that he had a talent amounting to a genius for the arrangement of natural objects according to system; that "He found biology a chaos; he left it a cosmos." But he extended his *Systema Naturæ* to cover the inorganic world from a logical desire to reorganize the entire field of natural history, rather than from an intelligent knowledge of rocks and minerals.

In the Linnæan system the first grand division of the mineral kingdom is into Petræ, Mineræ, and Fossilia ; but an examination of the substances arranged under these heads shows that the system expresses great ignorance as to the character and relations of many objects classified. Doubtless the followers of Linnæus, who were many and enthusiastic, were stimulated to much research as to the character of rocks and minerals, in their efforts to arrange them within the system of their master; but the most visible effect of the Linnæan system was to furnish a theme for controversial debate and argument for a century to come. The attempt to force inorganic substances into the same scheme of species, genera, etc., provided for plants and animals was warmly advocated on the one hand, and as fervently denounced on the other.

Development of mineralogy.—The latter half of the eighteenth century witnessed great advances in knowledge concerning the materials of the earth's crust, and toward its close there began to crystallize out of that knowledge the three sciences of mineralogy, geognosy, and petrography, although the latter was long unnamed.

With more and more accurate information as to the constant chemical composition of minerals, and under the influence of Haüy's brilliant conception of molecular structure and crystal form as attributes of these substances, mineralogy rapidly advanced to its place as a definite branch of science. Its subject-matter grew more and more homogeneous by a process of exclusion, as it became clear that many composite or impure substances had been erroneously classified with minerals. But the mineralogist of this period of development had little interest in and paid little attention to the heterogeneous aggregate of objects rejected from his category. Nevertheless mineralogists considered rocks as so plainly forming an appendix to mineralogy that they set up schemes for their classification based almost wholly upon mineral composition.

Foundations of petrography.— While mineralogy was thus developing on definite lines, the students of the mineral masses observed to have wide distribution in the earth were building up a vastly more complex science. By the careful researches of Pallas, de Saussure, von Buch, von Humboldt, Werner, Smith, Macculloch, and many others, the generalizations upon which stratigraphic geology is based were being formulated. The facts of an order in the superposition of strata were established in several localities and the genius of Werner was devoted to the framing of hypotheses explaining the observations made and providing for the extension of generalizations to the rock masses of the globe.

The foundations of petrography were laid in this period, the term rock (*roche*, *Gestein*) was frequently employed, and works termed classifications of rocks were published before the nineteenth century began. Thus in 1787 appeared Karl Haidinger's *Systematische Eintheilung der Gebirgsarten* (Vienna) and A. G. Werner's *Kurze Classification und Beschreibung der verschiedenen Gebirgsarten* (Dresden). The former essay, though awarded a prize by the St. Petersburg Academy of Sciences, appears based upon a superficial knowledge of rock masses when compared with the Wernerian arrangement. In these and other contemporaneous systems it is plain that the geological formation was not distinguished from the rock, as we now use these terms, and hence there was no true petrographical scheme at this time.

Werner's classification of rock formations.—Werner devoted much careful study to the mineral composition and general characteristics of rocks, and often described them in appropriate and precise terms. He distinguished between *simple* and *compound* rocks, and recognized that in many cases certain minerals were to be considered as *accessory* as compared with other *essential* constituents. Perhaps more than any other geologist he laid the foundations of *descriptive* petrography, but his systematic arrangement was so predominantly devoted to expressing a supposed order of superposition of rocks in the earth that it was rather a crude stratigraphic scheme than a classification of rocks which he presented. This will be clear from the outline given below.

Werner applied the term "formation" to masses of a certain character originating under certain conditions and perhaps recurring at various times in the history of the earth. Formations were grouped according to the great periods of their origin. He distinguished:

1. Primitive formations (*Das Urgebirge*): Under this head are found granite, gneiss, mica schist, clay slate, limestone, quartzite, porphyry, pitchstone, serpentine, and many other formations.

2. Transition formations (*Das Uebergangsgebirge*): Here were placed clay slate, graywacke, greenstone, gypsum, etc. The oldest fossils were supposed to occur in these rocks.

3. Stratified formations (*Das Flötzgebirge*): In this division are found sandstone, stone coal, marl, rock salt, various limestones, chalk, basalt, amygdaloid, and other formations.

4. Alluvial formations (*Das aufgeschwemmte Gebirge*): Here occur sand, clay, gravel, etc.

5. Volcanic rocks (*Vulkanische Gesteine*): This includes only lavas and ejectamenta of volcanoes, with several pseudovolcanic substances.[1]

The great majority of igneous and metamorphic rocks, as we now term them, were believed by Werner to be of aqueous origin, and were treated as such. In Werner's mineralogical system many rocks also found a place, as appears in von Kobell's statement of his system as it was in 1798. For example, under the clay family (*Thongeschlecht*) are included, among others, pitchstone, clay slate, basalt, wacke, clinkstone, lava, and pumice.[2]

DEVELOPMENT OF SYSTEMS IN THE NINETEENTH CENTURY.

At the beginning of the century, then, the attempts at the systematic classification of rocks were progressing on two very different lines. On the one hand the mineralogist, treating rocks as an appendage to mineralogy, was arranging them primarily by their mineral constitution, as far as he could determine it, and was for the most part uninfluenced by considerations of geologic origin or occurrence. His system was founded upon the most obvious characteristics of the objects in question.

On the other hand, the geologist was hampered by his efforts to arrange in one system geological terranes (formations) and rocks proper. He could not logically apply any criterion throughout the system, and was most inclined to use geological occurrence and theoretical considerations of origin.

The geologist's early classifications of rocks were naturally more complicated and less logically and consistently carried out than the schemes of mineralogists, and were correspondingly less satisfactory. But no classification of this period could have been really adequate, because the chemical and mineralogical compositions, as well as the origin, of many rocks were unknown, and only modern methods of research have permitted the assignment of a large number of types to their proper relationships.

---

[1] This general statement of Werner's elementary system I have taken principally from A. VON ZITTEL'S *Geschichte der Geologie und Paleontologie*, 1899, p. 89.

[2] F. VON KOBELL, *Geschichte der Mineralogie*, 1864, p. 165.

Abbé R. J. Haüy.—The first systematic arrangements of rocks to be of much importance to the science of petrography as now understood were evolved in Paris, and the controlling idea of these systems has dominated French petrography for a century, and is evident in all systems to some extent.

The Abbé R. J. Haüy was professor of mineralogy at the Museum of Natural History in Paris and in charge of its great cabinet of minerals. As already mentioned, his conception of molecular structure and its relation to crystal form had placed mineralogy within its proper sphere. In 1801 he published the first edition of his classic work "*Traité de minéralogie*," in four octavo volumes, with a fifth of quarto-size containing eighty-seven plates, filled for the most part with figures of crystals. This treatise is evidence at once of the advanced state of mineralogy and of the non-existence of anything worthy of being termed a science of rocks, in France, at this time. The quarto-volume of the *Traité* contains a tabular view of Haüy's "Distribution Méthodique des Minéraux." To this elaborate system of minerals are added two short appendices presenting an arrangement of rocks. One is headed "Agrégats des différentes substances minérales," the other, "Produits des Volcans." That the arrangement of rocks had not received much thought from Haüy at this time is clear from the imperfect scheme presented and from the fact that it was not until 1811 that Haüy addressed a letter to Leonhardt's *Taschenbuch für Mineralogie*, saying that he had conceived the idea of classifying rocks mineralogically ("J'ai conçu l'idée de classer cette suite (des roches) minéralogiquement").

Haüy was not a geologist, and his system must be judged in the light of the circumstances under which it was constructed. These are trenchantly characterized by Lossen in his comment that "the idea of mineralogical classification, of this great contemporary of Werner, did not spring from a wealth of geognostic observations; his letter [above referred to] was not dated from the central plateau of France, from Vesuvius, from the Rhone Valley, or from Predazzo, as were the classic letters of Leopold von Buch at an earlier day, but from the mineralogical cabinet in Paris.[1] Furthermore, the enlargement of the halls allotted to the collections and the consequent rearrangement of the latter was the immediate inspiration of the idea. Haüy's system is therefore characterized by Lossen as cabinet specimen petrography.

The writer does not know whether or not Haüy's revised system was actually published prior to the appearance of the second edition of his *Traité de minéralogie* in 1822. As there presented, it expressed at least ten years' development under the idea announced in 1811. Its principal feature is: a subdivision of rocks into classes, orders, genera, species, varieties, and modifications. Five classes of rocks are distinguished, viz.: (I) Stony and saline; (II) Combustible nonmetallic; (III) Metallic; (IV) Rocks of an igneous origin according to some, aqueous according to others; (V) Volcanic rocks. This grand division is clearly not logical or consistent. General, chemical, and physical properties and mode of origin are all arbitrarily applied. The stony appearance used to produce the first class is recognized as possessed also by the questionable igneous rocks of the fourth class, and is the first factor used for their further subdivision. A "schist inflammable" is included in the first class in spite of the property applied to produce the second class. Except for the class of metallic substances Haüy's category of rocks is similar to that now recognized as the subject-matter of petrography; that is, he did not include with them geological formations, as did many of his contemporaries.

The inconsequent construction of this system appears also in the factors used to produce three orders under the first class, viz.: (I) Phanerogenous ("phanerogène"); (II) Adelogenous ("adélogène"); (III) Conglomerate. The rocks of the first order are made up of definite mineral species, and their composition is apparent. The composition of those of the second order is not apparent to the naked eye, and it is assumed that portions of them do not belong to mineral species. Further, it is stated that some of them are clastic; but why these are not placed in the third order, which is defined as containing rocks composed of cemented particles of older rocks, is not discussed.

---

[1] K. A. LOSSEN. "Über die Anforderungen der Geologie an die petrographische Systematik." *Jahrbuch der königl. preuss. geolog. Landesanstalt und Bergakademie*, 1883.

The "cabinet petrography" of the mineralogist, as Lossen characterized it, is still more evident in the formation of genera, which in the first class, embracing the largest number of rocks, are named after minerals. The first genus is Feldspar, including not only rocks consisting mainly of feldspar, but also granite, syenite, pegmatite, protogine, gneiss, etc. Similarly, diorite is a species under the genus Amphibole. Haüy's system has always been criticised as giving entirely undue weight to certain minerals; but unnatural as is his scheme in that respect we have the same idea with us today, although it is no more logical now than it was a hundred years ago.

The criteria used in subdividing genera and species in Haüy's scheme are mainly those deemed of *primary* importance by later authorities. The *simple* and the *composite* are the leading heads under the genus, and structure is used to form varieties or modifications under the species.

John Pinkerton, 1811.—In 1811 there appeared in London a pretentious work of 1200 pages entitled: *Petralogy, a Treatise on Rocks*, by John Pinkerton, an Englishman. The author was an eccentric character, whose claim to renown rests rather on his historical researches than on his *Petralogy*, for he clearly had little conception of the objects under discussion in that work. The greater part of Pinkerton's energy was directed to a quaint and prolix argument against the tendency of the time to classify mineral substances in the same manner as animals and plants. His *bête noire* was the mineral *species*, for he insisted that the essential element of the species in the animal or vegetable kingdom was its power to "produce a similar progeny."

> Dr. Jameson tells us [remarks Pinkerton] that there is in fact but *one* species in mineralogy, namely, the globe; but even this may be doubted till it shall have produced another, at least as round and as wicked.

Admitting as appropriate the fundamental division of natural history into three kingdoms, the animal, vegetable, and mineral, Pinkerton ingeniously draws a distinction.

> In the two former [he remarks] the kingdom consists of living subjects, who, of course, may be well considered as divided into classes, orders, genera, and species; but in the mineral kingdom the territory alone constitutes the subject of discussion.
>
> But the very term mineral kingdom may of itself lead to a new and more proper nomenclature; for as a kingdom may be regarded as either vivified with animal and vegetable life, or as an inert tract of country, with certain geographical, chorographical, and topographical divisions; so the latter point of view can alone apply to mineralogy, while the former belongs to zoölogy and botany.
>
> What is more usual than the division of a kingdom into provinces, districts, domains, etc.? I would propose, therefore, in the present advanced state of the science, that the mineral kingdom be considered as divided into three Provinces:
>
> 1. Petralogy, or the knowledge of rocks, or stones which occur in large masses.
> 2. Lithology, the knowledge of gems and small stones.
> 3. Metallogy, or the knowledge of metals.
>
> Petralogy, a Province of mineralogy [is then] divided into twelve *Domains*; of which the first six, being distinguished by the substances themselves, may be called *substantial;* while the remaining six, being distinguished by circumstances or accidences of various kinds, may be called *circumstantial* or *accidential;* but this last division is of little moment.

The six "substantial" domains of Pinkerton are:

1. The Siderous, in which iron predominates.
2. The Siliceous.
3. The Argillaceous.
4. The Magnesian.
5. The Calcareous.
6. The Carbonaceous.

The "accidential" domains are:

7. The Composite.

8. The Diamictonic, "in which substances are mingled."

9. The Anomalous, "or those which contradict the common order of nature."

10. The Transilient.

11. The Decomposed.

12. The Volcanic.

This outline will indicate sufficiently that the *Petralogy* has no real importance to the present review. Pinkerton does not appear to have been taken seriously by his contemporaries, as there is little or no reference to his elaborate system in succeeding publications of his countrymen.

Alexandre Brongniart, 1813.—In 1813 Alexandre Brongniart[1] published a *Classification minéralogique des roches mélangées.* The writer has not seen the original, but von Leonhard gives a tabular view of the scheme proposed by Brongniart, which shows it to have been crude, and not worthy of special discussion here, because of the much more elaborate and mature work by this author issued a few years later, to which some space must be given. But comparatively crude as this outline was, it gave much evidence of the logical mind of its author.

P. L. A. Cordier, 1815.—Contemporaneously with the constructive labors of Haüy and Brongniart, another French master was also struggling with the same problem. It is to the painstaking researches of P. L. A. Cordier that we owe the first great step in deciphering the composition of volcanic and other rocks of such fine grain that their constituents could not be recognized by the simple methods of examination then in use. He instituted chemical, microscopical, and mechanical researches of much ingenuity, and arrived thus early at the conclusion that volcanic rocks were made up of known minerals in microscopic crystals or grains, and of glass, which he believed contained the same elements. In 1815 Cordier presented to the Academy of Science in Paris the results of his investigations in an important work upon the substances composing volcanic rocks.[2] The classification of volcanic rocks accompanying his memoir was limited to the few surface lavas then known and the tuffs and ashes. He had the idea that either feldspar or pyroxene predominated in all cases, and hence the first division was into feldspathic and pyroxenic rocks. Texture was the main property applied for further subdivision.

---

[1] *Journal des Mines*, Vol. XXXIV.

[2] P. LOUIS CORDIER, "Mémoire sur les substances minérales dites *en masse*," etc., followed by "Distribution méthodique des substances volcaniques dites *en masse*,"

John Macculloch, 1822.—The third decade of the century witnessed the publication of several important essays in rock classification. The first of these was by John Macculloch, and was entitled *Geological Classification of Rocks, with Descriptive Synopses, Comprising the Elements of Practical Geology*, issued in London, 1822. Macculloch's work is called "a classification of rocks," but it is really a classification of rock formations, as we should now express it. It is an attempt at stratigraphic geology without recourse to fossils. Its foundation was a knowledge, which was very thorough for the time, of the rocks of a limited area, and the assumption that the same rocks must, in general, occur in all parts of the world in the same sequence and relations as in the British Isles. In discussing the basis of his scheme he says:

> In considering the different plans on which a classification of rocks might be constructed, he (the author) was, without hesitation, led to adopt one founded on the geological relations and positions of rocks in nature . . . . the basis of the arrangement is virtually the same as that adopted by Werner.

Macculloch thought that all rocks might be placed in a few groups, distinguished by certain prevailing mineral characters.

> It will be further seen [he says] that these different groups are also in a great measure distinguished in nature by certain general or geological relations, more or less constant and perfect.

The arrangements according to mineral characters and geological relations were believed to coincide.

The attempt to use fossils as criteria of the age of rock formations, which was then being made by the Germans, did not appeal to Macculloch. He is said to have been jealous of the

---

Journal de Physique, 1815–1816. Both memoir and table of classification were reprinted by D'Orbigny in 1868, in his work *Description des roches*, etc., which gave the system of Cordier as elaborated at the time of his death, in 1861.

rapidly developing science of palæontology. In his opinion fossils were not well enough known, as to their kinds or their distribution, to be used as factors in classifying rocks as to their geological position. He says, however, that he looks forward to the time "when a system of organic mineralogy will be formed."

With regard to his system Macculloch remarks:

> The classification is simple; all rocks being referred to a primary and a secondary class, and a smaller division being formed of those which are found in both. The substances which cannot be referred to the latter class, from their more recent origin are considered separately in an *appendix;* and a similar expedient is adopted for the volcanic rocks.

"Primary" means to Macculloch anterior in date to the secondary; and "secondary" means later than the primary. Each class is divided into two divisions, the *Stratified* and the *Unstratified.* "As these subdivisions," remarks the author, "have not yet been introduced into any of the arrangements of rocks, they will each require some explanation."

The result of Macculloch's scheme is expressed in the following tabular arrangement of rocks:

PRIMARY CLASS.

Unstratified.

Granite.

Stratified.

Gneiss.
Micaceous schist.
Chlorite schist.
Talcose schist.
Hornblende schist.
Actinolite schist.
Quartz rock.

Red sandstone.
Argillaceous schist.
Diallage rock.
Limestone.
Serpentine.
Compact feldspar.

SECONDARY CLASS.

Stratified.

Lowest (red) sandstone,
Superior sandstones.

Limestone.
Shales.

Unstratified.

Overlying (and venous) rocks.

Pitchstone.

OCCASIONAL ROCKS.

Jasper.
Siliceous schist.
Chert.
Gypsum.
Conglomerate rocks.
Veinstones.

Appendix.

Volcanic rocks.
Clay, marl, sand.
Coal.
Alluvia.
Lignite.
Peat.

If we examine this table, it is seen that Macculloch was not able to carry out consistently the application of the factors adopted. This is most conspicuously the case with the "overlying (and venous) rocks" placed in the unstratified division of the secondary class. These overlying rocks were, in fact, recognized as later than the secondary rocks in many cases. They are mainly what we should call intrusive igneous rocks, found cutting other rocks, and of the real age of which Macculloch confessed that he had little evidence. He was ignorant of the composition of aphanitic or felsitic rocks, and they receive no consistent treatment at his hands.

Macculloch is credited with having been a keen observer and with having made truly great contributions to stratigraphic geology. But he does not appear to have conceived of the distinction between a geological formation and a rock. There are in his book many phrases, such as the title of the work itself, and statements scattered through it, which are couched in the language of today, but have very different significance at this time. It is interesting to apply many of his remarks concerning the condition of the systematic science of rocks, as understood by him, to the petrography of today.

Karl Cæsar von Leonhard, 1823.—In 1823 appeared a truly epoch-making work, the *Charakteristik der Felsarten* by Karl Cæsar von Leonhard, professor at the University of Heidelberg. This is, in fact, the first fairly consistent treatise upon rocks. It is founded upon an exceptionally accurate knowledge of the objects classified, and with advanced ideas as to the true relations between geognosy proper and the descriptive science of rocks. Yet von Leonhard did not give his science a name, and presents it as a part of geognosy.

Von Leonhard says that his object is to present all facts bearing upon the *character* of rocks, an aim expressed in his chosen title. He points out that a discussion of the stratigraphic relations of rocks must be preceded by an accurate statement of their nature. Rocks are defined as the mineral masses of more or less considerable extent in the crust of the earth. It is recognized that, from the standpoint of geognosy proper, only those masses can be considered important the extent of which is so considerable that general laws as to their relations and distribution may be discerned. Yet it is pointed out that there are other masses of subordinate or abnormal occurrence which may have a wide distribution, though occupying no position peculiar to themselves, and that these masses are important when arranged by their characteristics. Stratigraphic geology and petrography are thus fairly outlined, though no definite proposal for their separation is made.

The classification presented by von Leonhard has many features which are preserved in modified form in the German systems of today. Like all early systems, however, the primary division is arbitrary, and drawn upon no definitely stated principle. Four divisions are established : (1) Heterogeneous rocks, (2) Homogeneous rocks, (3) Fragmental rocks, (4) Loose rocks, while coals are placed in an *appendix*. For subdivision, structure is used as the basis, the granular, schistose, porphyritic, dense, and glassy groups being established in some of the main divisions. These terms are used with nearly the meaning we now attach to them. The principal anomalies of association in the arrangement arise from the throwing together of igneous and sedimentary rocks in certain groups, and from the inconsequent way in which von Leonhard met the difficulty of dealing with the more or less dense rocks, the composition of which could not then be ascertained. These were mainly of igneous origin, and not stratigraphic units, and there was no proper place for them in the system. They were treated as a group by themselves under the Homogeneous rocks, with the heading, "Rocks (apparently homogeneous) which are not to be regarded as minerals" ("Nicht als Glieder oryktognostischer Gattungen zu betrachtende—scheinbar gleichartige—Gesteine"). Here we find trachyte, aphanite, serpentine, basalt, pitchstone, obsidian, and various schists. Von Leonhard realized more or less clearly that most of these rocks would some day be found to be complex in character, and he therefore appreciated that his treatment of them was a makeshift. Twelve years later, in his *Lehrbuch der Geognosie und Geologie*, he raised the *apparently homogeneous* rocks to an equal rank with the heterogeneous and homogeneous divisions.

Von Leonhard was unquestionably the foremost petrographer of his day, sharing with Alexandre Brongniart the honor of first placing the classification of rocks upon a firm basis as a systematic science. He had been called to Heidelberg but a few years before this work was issued, finding there perhaps the largest collection of rocks then in existence. He had also visited Paris and studied the great collection of the Museum of Natural History as arranged by Haüy. Von Leonhard also belonged to the group of German geologists who, with Smith and Macculloch in England, and a few elsewhere, were engaged in placing stratigraphic geology upon a sure foundation. He did not himself develop the distinction, clearly foreshadowed in his work, between the geological formation and the rock.

A critical examination of the system contained in the *Charakteristik* shows that von Leonhard actually applied as his first criterion the distinction between massive and clastic rocks, as we should express it, though he may not have realized it. Next he applied the idea of homogeneity and its opposite. But the notable feature is the prominence given to structure and the close approximation of some of his definitions to ones in current use. It was the first time structure was assigned so prominent a rôle in a system of rocks. Mineral composition followed structure, and was applied quite reasonably.

The system of von Leonhard is specially noteworthy as the work of a German, for in it he breaks away from the influence of the Wernerian school. This was doubtless to some extent the result of a visit to Paris, but while building upon the characteristics of rocks he did not give to mineral composition the completely dominating place which it held in the French systems. Von Leonhard rejects the biological framework of classes, orders, genera, and species as quite inapplicable to rocks, since they lack individuality.

Alexandre Brongniart, 1827.—The *Classification et charactères minéralogiques des roches homogènes et hétérogènes*, by Alexandre Brongniart, published in 1827, marks the next important step in the development of petrography. This admirable little book of only 144 pages contrasts markedly with other voluminous works of its period. It is concise in statement, and presents a clearly conceived and logically worked out system.

In the introduction we find minerals, rocks, and geological terranes distinguished and defined. *Minerals* are species or varieties determined by the laws of mineralogy; *rocks* are the same substances considered in their masses and as entering into the structure of the globe; *terranes* are assemblages of several rocks, considered as having been formed at about the same epoch. Brongniart pointed out that there were two ways of looking at rocks—as to their composition, and as to their occurrence. He held that geognosy was not strictly a classification of rocks; that to arrange rocks by occurrence and describe them in that order involved many digressions from the discussion of relationships; that rocks formed at different times must then be referred to as many times as they occurred; that the same name would be given to different substances formed at the same time; and, finally, that classification by occurrence involved the use of hypotheses where knowledge was lacking. All these troubles should be avoided, in his opinion, by classifying and naming rocks upon mineralogical composition and independently of occurrence. The treatment from the latter standpoint could then follow naturally.

The system of Brongniart is a mineralogical classification with the aid of the exterior characters. His divisions are styled classes, orders, genera, and species. There are but two classes, viz.: (1) "Roches homogènes ou simples;" (2) "Roches hétérogènes ou composées." In this respect Brongniart is more logical than von Leonhard. The *Homogeneous rocks* are defined as those that *appear to be so* to the naked eye. There are two orders under the class of *Homogeneous rocks*, namely: (1) "Roches phanérogènes (of distinct known mineral species); (2) "Roches adélogènes" (of unrecognizable constitution). This division is logical enough, but it is based on a criterion of primary value which is clearly applicable to *all* rocks. The result is that under Homogeneous rocks are included, in the second order, a number of substances, including clays, dense schists, trap, basalt, and other igneous rocks, of really heterogeneous character.

The Heterogeneous rocks are also divided into two orders: (1) "Les roches de cristallisation; (2) Les roches d'agrégation." This distinction really introduces the factor of conditions of origin, which fact Brongniart seemingly did not recognize, as he makes no comment upon it.

When it comes to finer subdivision we find that this system is almost purely mineralogical, as its title claims. Structure is relegated to a very subordinate rôle, wherever it is convenient to apply it.

Systems of von Leonhard and Brongniart compared.—If we now review the construction of the systems proposed by von Leonhard and Brongniart, which may be taken as the real starting point of systematic petrography, we find that both resorted at once to an expedient which expressed the fact that in their day the composition of many rocks was unknown. And the principal inconsistencies of the two arrangements came from their treatment of the aphanitic rocks of all kinds throughout the schemes. But we must admit that these substances could not be correctly classified by composition so long as their character was so nearly unknown.

Both these masters relied mainly on *mineral composition*, but von Leonhard advanced *structure* also to a prominent place. Both declared that the system and nomenclature of rocks should be founded upon *characteristics*, and that the various treatments rocks must further receive from the geologist would be facilitated rather than retarded by such an arrangement. Brongniart made a suggestion, apparently unconsciously, in subdividing Heterogeneous rocks, that geological conditions of origin might serve as a practical basis in classification; but he made only limited application of that factor, and does not appear to have grasped the broader meaning of his own proposition.

After von Leonhard and Brongniart had placed petrography upon a firm basis, no great advance was made in the systematic part of the science until the middle of the century. The cause of the unsatisfactory elements in the early schemes was recognized to lie in the ignorance concerning the character of many rocks, and a large number of investigators devoted themselves to the study of the composition of rocks on the one hand and to their geological relations on the other. While the object of this review is to trace the application of principles or of knowledge in classification rather than to follow the course of investigation, it is necessary to refer briefly to the studies made during the second quarter of the century, noting the use of new knowledge in system.

Investigations into the chemical composition of rocks.—Among the characters of rocks not taken into appropriate account in the first systems, by far the most important is *chemical composition.* But from the beginnings under Cordier more and more attention was paid to chemical investigation, until other things became quite subordinate. First, qualitative test was applied, then partial analysis, and finally bulk analysis. Chemical research was naturally applied with most valuable results to the denser rocks, chiefly of igneous origin, and in this way, with ever-extending field investigation, it was found that these substances were vastly more complex, more varied in character, and much more common than had been supposed. From these causes the petrography of igneous rocks grew to be the principal part of the science instead of being relegated to an "appendix," as had been done at an earlier day.

The chemical analysis of igneous rocks was mainly directed to a determination of their mineral constituents and to the question as to whether the various oxides were present in simple or constant proportions or not. For the latter inquiry the ratio of the oxygen contained in the silica to that of the bases, taken together or in groups, was calculated and comparisons instituted. G. Bischof set up as a means of comparison the so-called "oxygen quotient," obtained by dividing the total oxygen of the bases by that of the silica, as shown in the analysis of any given rock. That the faulty analyses of the time could not in any case have yielded trustworthy evidence of stoichiometric or constant proportions of the constituents is now clear; but even with the imperfect analyses the complexities of the problem were such as to lead nearly all chemical students of rocks to abandon attempts to deduce chemical formulæ or simple ratios for them.

For many years chemical investigations were necessary in determining the approximate mineral composition of many rocks, and important discoveries were undoubtedly made; but it is pathetic to recall the years spent in hard labor by many of the foremost men of their time in endeavoring to work out the mineral composition of fine-grained or aphanitic rocks from incorrect or inadequate bulk analyses, and with very imperfect knowledge of the constitution of some rock-making minerals. Abich, Bunsen, von Waltershausen, Bischof, Scheerer, Roth, Streng, Delesse, Haughton, and many others devoted much time to this research without what appears to us, at this time, to have been commensurate results.

Classification by feldspars.—The principal effect of this chemical work upon petrographic classification appears to have been to perpetuate the mistake of giving an undue importance to the feldspars as rock constituents. As different kinds of feldspar were recognized by chemical analysis, largely through the researches of Gustav Rose, a further mistake was made. It was for a time thought that orthoclase (or potash feldspar), albite, oligoclase, labradorite, and anorthite were the only feldspar species entering into rocks, and that they did not occur to any great extent in association. Hence, after setting up a great division of *feldspathic rocks*, the logical method for subdivision was according to the kinds of feldspar present. This was thought to be the more surely a correct principle, since its application seemed to produce groups nearly coinciding with those previously recognized, but less sharply defined.

Perhaps the first to advocate the use of feldspars in this way was Hermann Abich, in 1841.[1] Abich viewed magmas as basic, neutral, or acid silicate solutions of a great range in specific gravity. As the known feldspar series presented also a wide range in silica and in specific gravity, it seemed to him certain that there must be a definite relation between the silica content of a given magma and the feldspar which could crystallize out of it. It therefore seemed to him possible to use the various feldspars for the classification of endogenous (or eruptive) rocks very much as fossil remains were used in sedimentary rocks. For the next twenty-five years a sharp division according to feldspars was advocated, in systems to be reviewed; and it required the application of the theory of isomorphous mixtures to feldspars, the polarizing microscope, and modern methods of mechanical and chemical analysis, to demonstrate the true distribution of feldspars in rocks, and the thoroughly artificial nature of this arrangement.

Influence of genetic hypotheses.—The connection of chemical composition of igneous rocks with theories as to the origin of the differences in composition of magmas and the use of the genetic conception in classification forms an interesting chapter in the history of systematic petrography. Yet the application of this genetic idea led at first only to a broad and ill-defined proposition in classification which does not require full discussion in this place. Reference is had to Bunsen's hypothesis of two fundamental magmas—the trachytic and the pyroxenic—mixtures of which were supposed to produce all igneous rocks.[1] From the systematic standpoint Durocher's hypothesis had the same result, though differing somewhat from Bunsen's in the physical origin of the magmas. Durocher (1857) carried out a chemical division of igneous rocks on his hypothesis, forming the *acid*, *hybrid*, and *basic* groups.[2] Th. Kjerulf[3] (1857) proposed four chemical groups: *acid*, *neutral*, *basic*, and *ultra-basic*, and various authors recognized the grand division of *acid* and *basic*. Such divisions, when closely connected with hypotheses, have had more influence upon the geologist than upon the systematic petrographer; for it was quickly found that, although the fundamental idea might be near the truth, the theory was too imperfect (or narrow) to explain the observed range in chemical composition of igneous magmas. The broad chemical distinction, considered merely as a recognition of the observed range in composition of rocks, was not given sufficient precision to be of much value in system.

---

[1] H. ABICH, *Geologische Beobachtungen über die vulkanische Erscheinungen und Bildungen in Unter- und Mittel-Italien*, Braunschweig, 1841.

Geological classifications.—During these years of patient research, especially into the composition of igneous rocks, geologists were making important contributions to the broader phases of classification. As a knowledge of occurrence, relation, and modes of formation of rocks increased many different factors were tested as to their applicability to the formation of systematic arrangements. Soon the numerous geological standpoints from which rocks might be viewed and classified led to a great many schemes for their arrangement, and much confusion existed. This condition continued until the geologist separated the systematic classification of rocks from various other arrangements of which these bodies were found capable. Certain geologists, as, for instance, De la Beche in England, had, at an early day, very clear and logical ideas as to the principles which must control classification. In the third edition of his *Geological Manual,* issued in 1833, is the sentence: "Classifications of rocks should be convenient, suited to the state of science, and as free as possible from a leading theory." In accordance with this principle, De la Beche divided all rocks (including formations) into *stratified* and *unstratified,* "independent of the theoretical opinions that may be connected with either of these great classes of rocks." The stratified rocks were then subdivided into "superior or fossiliferous" and "inferior or non-fossiliferous." By this logical division De la Beche at once secured classes or subclasses corresponding well to those now called igneous, metamorphic, and sedimentary.

---

[1] R. BUNSEN, "Ueber die Processe der vulkanischen Gesteins-bildungen Islands," *Poggendorf's Annalen*, etc., Vol. LXXXIII, 1851, pp. 197–272.

[2] J. DUROCHER, "Essai de pétrologie comparée," etc., *Annales des Mines* (5) Vol. XI, 1857, p. 217.

[3] *Nyt magazin for naturvidenskaberne*, Vol. IX, 1857, p. 294.

Carl Friedrich Naumann, 1850, 1858.—Without attempting a complete history of the introduction of each factor into classification, we will now consider the system of Carl Friedrich Naumann, the great Saxon geologist, as of much importance in presenting *a new mode of treatment.* The first edition of his *Lehrbuch der Geognosie* appeared in 1850, the second in 1858. Naumann was a great systematist; he viewed rocks from many standpoints, and from each constructed a peculiar scheme of treatment. Thus one section of the *Geognosie* was called "Petrographie oder Gesteinslehre," defined farther as a branch of "Chthonographie oder die Geognosie im engeren Sinne des Worts." This is the first use of *petrography* of which I have knowledge. It is used in the sense of petrology, as the latter term is now commonly applied in America.

Naumann not only gave the comprehensive science of rocks a special name, but he established within it six divisions, namely:

A. Hylology, a discussion of the constituents of rocks.
B. Histology, on texture and structure of rocks.

C. Morphology, a classification of forms of occurrence.
D. Synopsis, or the systematic descriptive science.
E. Petrogeny, a discussion of the genesis of rocks.
F. Allo-osology, the science of the alteration of rocks.

Under this elaborate framework rocks were grouped in many ways. They were considered as minerogenous, zoögenous, or phytogenous, according to origin of materials; as crystalline, clastic, dialytic, or amorphous, depending on character of the constituent grains; as simple or composite; in another view as phanomeric or cryptomeric, and so on.

But when it came to the systematic arrangement of his "Synopsis" Naumann was at sea. He himself called it an *attempt* at a grouping of rocks—"Ein Versuch einer Gruppirung der Gesteine"—and plunged without discussion of principles into the description of rocks under a scheme of classes, orders, families, and lesser divisions.

In the first edition of the *Lehrbuch*, Naumann divided all rocks into three classes, namely: (1) Crystalline rocks; (2) Clastic rocks; (3) Rocks which are neither crystalline nor clastic.

It was explained that the groups of amorphous, zoögenous, and phytogenous rocks are scarcely co-ordinate in importance with the crystalline and clastic divisions, so they were united in the third composite class. In the descriptions of the Synopsis, however, the amorphous (hyaline and porodine) rocks were considered in connection with the rocks of the other two classes to which they are related in composition.

In the second edition but two classes were recognized, embracing all rocks: (1) Protogenous (original); (2) Deuterogenous (derived). Naumann gave no discussion of the basis upon which he made the change.

In both editions Naumann leaves the manner of subdividing classes to the reader to make out for himself. In the class of original rocks are six orders, viz.: (1) Ice, (2) Haloid rocks, (3) Quartz rocks, (4) Silicates, (5) Ores, (6) Coal. Families are produced within these orders by mineral composition. Structure, texture, and other properties are occasionally used for minor unnamed divisions. After the elaborate preparation for this arrangement, it must be confessed that Naumann failed utterly to produce a system worthy of the name. No logical and consequent application of principles can be found in his Synopsis.

The great value of Naumann's work lies in the clear setting forth of the scope of the *general science* of rocks, independently of their formal or historical relations to the earth. He outlined the divisions under the broad science, and showed the proper position of the purely systematic and descriptive branch. He illustrated clearly how many arrangements or groupings of rocks are natural and necessary from the geologist's standpoint, and evidently understood that he could not introduce all these considerations into the construction of one system of classification.

In the development of petrographical system, Naumann's analysis of the broad science was of great importance. For many years the primary classification of rocks, leading to an arrangement for purposes of description, followed some of the various ways set forth by him. And even at the present day we find H. Credner, a successor of Naumann in the university at Leipzig, presenting rock descriptions in his well-known *Elemente der Geologie* under a framework very similar to that of the *Lehrbuch der Geognosie.* Whatever the choice of criteria adopted by individuals from among the alternatives presented by Naumann, very similar, if not identical, major divisions were formed.

Bernhard von Cotta, 1855, 1862.—Almost contemporaneously with Naumann's *Geognosie* appeared several other treatises on rocks by German authors of note. *Die Gesteinslehre*, by Bernhard von Cotta, was first published in 1855, and its second edition in 1862, the latter being translated into English and serving for years as a standard work.

The first edition of the *Gesteinslehre* professes to be merely a description of rocks, and the arrangement or order in which the various kinds are presented is stated to be one of convenience only. Von Cotta's point of view was that, as rocks are simply aggregates of mineral particles, one kind grading into another, and as they are of different modes of origin, there can be no species comparable to those of plants, animals, or minerals, and hence a classification, properly speaking, is an impossibility. Reviewing the various characters of rocks as to their application in nomenclature and description, this author touches on some fundamental points with noteworthy discrimination. This is particularly true with regard to his remarks on the availability of texture for purposes of classification. Noting that it is the most easily distinguished character of rocks, and that it had been used as a primary factor in classification, he pointed out that chemical and mineral composition were more fundamental, and that there was nothing so intrinsically important in texture that differences in that respect should be allowed to separate things otherwise alike.[1] It seemed to him better to name the rock from its mineral composition, and for textural varieties to add expressive terms.

In this first edition of the *Gesteinslehre*, von Cotta introduced no geological factor into his adopted arrangement. He treated all rocks in the following groups, which were purely for convenience :

1. Basaltgesteine.
2. Grünsteine und Melaphyre.
3. Trachyte.
4. Porphyre.
5. Granite und Gneisse.
6. Glimmerschiefer.
7. Thongesteine.
8. Kieselgesteine.
9. Kalksteine und Dolomite.
10. Gypsgesteine.
11. Verschiedene Mineralien als Gesteine.
12. Eisengesteine.
13. Kohlen.
14. Trümmergesteine.

In the second edition of the *Gesteinslehre*, issued in 1862, while still claiming rocks to be incapable of true classification by inherent characters, von Cotta makes a noteworthy advance toward a systematic arrangement by grouping them primarily according to geological mode of origin. As further factors he uses, in certain classes, broad chemical distinctions and form of occurrence. His general scheme is as follows :

---

[1] "Genau genommen ist indessen die Textur gar nichts so wesentliches, dass sie veranlassen könnte, wegen ihrer Ungleichheit zwei Gesteine ungleich zu nennen, wenn sie übriges gleich sind."—*Gesteinslehre*, p. 22, 1855.

- I. Eruptive rocks, probably all originating through consolidation from a molten condition.
  - 1. Poor in silica, or Basic.
    - *a.* Volcanic.
    - *b.* Plutonic.
  - 2. Highly siliceous, or Acid.
    - *a.* Volcanic.
    - *b.* Plutonic.
- II. Metamorphic crystalline schists, probably all derived from sediments, yet resembling eruptive rocks in mineral composition.
- III. Sedimentary rocks.
  - 1. Argillaceous.
  - 2. Calcareous.
  - 3. Siliceous.
  - 4. Tuffs.

To these three clearly defined groups was added an appendix of rare rocks or those of problematic origin. Here were included many quartzose rocks, coals, iron ores, serpentine, etc.

The eruptive rocks were considered as derived from molten magmas; the broad chemical distinction was made with Bunsen's law in mind, but not directly as its expression; the volcanic and plutonic rocks were separated purely on the basis of occurrence; the further subdivision was by general mineral composition, and texture was used as subordinate to it. It is worthy of special note that von Cotta expressly pointed out that geological age was not involved in the distinction between the volcanic rocks and the plutonics. He considered that the older volcanics had been largely removed by erosion, and that the younger plutonics had not yet been laid bare.

Ferdinand Senft, 1857.—In 1857 appeared an elaborate work by Ferdinand Senft, with the title (translated) *Classification and Description of Rocks, Founded upon their Mineral Constitution, Chemical Composition, and Structure.*[1] This treatise, which received the Demidoff prize (St. Petersburg), is mainly notable for its elaborate attempt to apply chemical factors in details of classification.

---

[1] "Classification und Beschreibung der Felsarten, gegründet auf ihre mineralogische Beschaffenheit, ihre chemische Zusammensetzung und ihre Structur," Breslau, 1857.

In this work Senft gives detailed tables for the determination of rocks, the first of which presents the following general scheme of classification:

A. Inorganic rocks ("Anorganolithe").
  I. Crystalline.
    1. Simple.
    2. Composite.
  II. Clastic.
    a. Indurated.
      1. Pseudoclastic.
      2. Hemiclastic.
      3. Holoclastic.
    b. Unconsolidated.
      1. Gravel, sand, etc.
      2. Soil ("Erdkrumer").
B. Organic rocks.

Curiously enough Senft's discussion of principles of classification begins with the consideration of the means for subdividing the smallest divisions of this table, which he calls "Classes."

Senft believed that rocks of these classes should be further arranged by their characters. Reviewing these, he points out the great difficulties in so classifying them, owing to the fine grain, variable composition and texture of many kinds. The facts lead him to assert that the main systematic divisions, such as orders, groups, etc., cannot be founded on structure (Gefüge) or other outer habit of the rocks, because the former factor would at once separate similar things, and the latter bring different things together. Mineral composition would be the best basis for arrangement were it not for the fact that, in the fine-grained or aphanitic rocks, chemical tests are necessary to determine the mineral components. As it is, the chemical relation of rocks—and especially of the crystalline—to certain solvents affords the only safe means by which rocks can be classified. This factor of solubility is actually applied to the formation of orders, suborders, and groups under the classes provided by the scheme already outlined. Senft is, however, not fully consistent, for the first division of the class of composite crystalline rocks is on mineral composition, into the two orders: (1) Alabradorites (rocks free from labradorite, generally rich in quartz, and never containing augite); (2) Labradorites (rocks characterized by labradorite and free from quartz and orthoclase). These were subdivided into nine groups, according to the action of hydrochloric or sulphuric acid upon the rocks. For further details of this unique and highly artificial system the reader must be referred to the original work.

J. Reinhard Blum, 1860.—Shortly after the treatises of Naumann, von Cotta, and Senft, there was published the *Handbuch der Lithologie oder Gesteinslehre*, by J. Reinhard Blum.[1] This work is but little more than a descriptive handbook, with slight discussion of principles of classification, and in it no original contribution to the systematic science was made. The main divisions of the work are as follows:

I. Crystalline rocks.
  A. Homogeneous.
    a. Granular.
    b. Schistose.
    c. Porphyritic.
  B. Heterogeneous—with three structural divisions.
II. Clastic rocks.
  A. Cemented.
  B. Not cemented.

The further division of crystalline rocks is by mineral composition.

Justus Roth, 1861.—Among the students of the chemical composition of igneous rocks none has rendered greater service than Justus Roth, who, in 1861, published his *Gesteinsanalysen, in tabellarischer Übersicht und mit kritischen Erläuterungen.* Upon the basis of nearly a thousand analyses available at that time, Roth undertook to ascertain whether chemical composition gave in itself a practical ground for the classification of igneous rocks. As a basis for comparison of analyses Roth selected the oxygen ratio, *i. e.*, the ratio of the oxygen of the acid radical, SiO_2, to that of the bases, RO (including R_2O) and R_2O_3, and obtained the oxygen quotient (originally proposed by Bischof) by dividing the oxygen of the bases by that of silica.

---

[1] *Erlangen*, 1860, pp. 356.

Comparing all available analyses in this way Roth recognized that no simple chemical relations existed between different rocks, and that chemical formulæ were therefore useless; that rocks of different mineral composition fell in the same chemical division; that chemical and mineral arrangements of rocks could not coincide; that a purely chemical arrangement would separate things closely related on geological and mineralogical grounds; and that a mineralogical arrangement must be connected with structure and texture. In this dilemma Roth chose to arrange igneous rocks primarily by their kinds of feldspar and the presence or absence of quartz. He admits that pyroxene or amphibole might be used in the same way, but considers feldspar much preferable because of its greater abundance and easier determination. The scheme of classification presented by Roth is as follows:

I. Orthoclase rocks (often containing some oligoclase).
  A. With quartz (*i. e.*, more siliceous than orthoclase).
    1. Granite.
    2. Gneiss.
    3. Felsite porphyry.
    4. Liparite.
    5. Syenite.
  B. Without quartz.
    1. Orthoclase porphyry.
    2. Sanidine trachyte.
    3. Sanidine-oligoclase-trachyte.
    4. Phonolite.
    5. Leucitophyre.
II. Oligoclase rocks.
  A. With hornblende.
    1. Diorite.
    2. Porphyrite.
    3. Amphibole andesite.
  B. With augite.
    1. Oligoclase-augite-porphyry.
    2. Melaphyre and spilite.
    3. Pyroxene-andesite.
    4. Nephelinite.
    5. Haüynophyre.
III. Labradorite rocks.
    1. Labradorite-porphyry.
    2. Gabbro.
    3. Hypersthenite.
    4. Diabase.
    5. Dolerite.
    6. Normal pyroxenic rock (Bunsen.)
    7. Basalt.
IV. Anorthite rocks.
  A. With augite — eukrite.
  B. With hornblende.

This arrangement attempts no expression of a relation between chemical and mineral composition; it assumes constant presence of feldspars in some amount in all rocks, and also certain characteristic associations of minerals. It indirectly recognizes structure and geological age as factors in classification. Roth believed that the classification by mineral components outlined certain combinations or associations as central points of notably frequent and widespread occurrence, about which the rocks of other combinations and of comparative rarity must be grouped. While expressing the idea that not only the kind but the amount of various minerals might be considered in a mineral classification, he confined his own adaptation of this idea to the recognition of *essential* and *accessory* constituents, in certain cases, and with no definite plan.

Th. Scheerer, 1864.—Shortly after the appearance of Roth's tables of rock analyses, a proposition for the general classification of igneous rocks upon a chemical basis was published by Th. Scheerer.[1] This proposition is notable as representing the views of one of the men who, in the preceding decade, had devoted much time and labor to the bulk analysis of rocks. Unlike Roth, who had come to the belief that no simple and persistent chemical formulæ or ratios could be set up for igneous rocks, Scheerer was convinced that he had found such formulæ, and that all silicate rocks could be referred to nine comparatively simple chemical types.

Upon the basis of earlier investigations of the gneisses of the Saxon Erzgebirge, Scheerer had come to the idea that all of them could be considered as mixtures of three magmas, represented in nearly pure form in three prevalent gneisses of the region, namely: the "Rother Gneiss," "Mittlerer Gneiss," and "Grauer Gneiss," the composition of which might be expressed in simple formulæ, given below. The visit to the Fassathal was made to test the general applicability of this threefold division to other highly siliceous rocks, and to gather from the numerous basic rocks of that region material for chemical investigations which might show the feasibility of classifying all rocks in a similar manner.

---

[1] "Vorläufige Bericht über krystallinische Silikatgesteine des Fassathales und benachbarter Gegenden Südtyrols," *Neues Jahrbuch für Mineralogie*, etc., 1864, pp. 383–411.

Upon scrutiny of his material and study of analyses of rocks from other localities, Scheerer was persuaded that all highly siliceous igneous rocks could be referred to the three magmas represented by the Saxon gneisses above mentioned, or to mixtures of these magmas. The intermediate and basic rocks he believed could in a similar manner be assigned to six definite chemical types, and in the cited publication Scheerer outlined this chemical classification.

Scheerer's system expresses the idea that the molten material below the solid crust is arranged by specific gravity in zones, each of quite simple stoichiometric composition. He further believed that the upper, more siliceous magmas were first erupted, and the basic ones in late geological periods. From this cause the earliest rocks might be supposed to represent the fundamental magmas more nearly than the basic ones, since the latter magmas must have passed through rocks of varied constitution in reaching the surface, and, therefore, suffered much modification through the fusion and assimilation of fragments torn loose in ascending.

The nine chemical types of Scheerer were arranged in three groups, and named from rocks deemed to represent them in purest form.

	Oxvgen Ratio $SiO_2 : RO+R_2O_3$ (= 1).	Oxygen Quotient.	Mean silica Percentage.
PLUTONITES:			
Upper = "Rother Gneiss"......	4.50	0.222	75
Middle = "Mittlerer Gneiss"....	3.75	0.267	70
Lower = "Grauer Gneiss"......	3.00	0.333	65
PLUTO-VULCANITES:			
Upper = Quartz-bearing syenites.	2.67	0.375	63
Middle = Syenite..............	2.33	0.429	60
Lower = Melaphyre.............	2.00	0.500	55
VULCANITES:			
Upper = Augite-porphyry......	1.50	0.667	48
Middle = Common basalt.......	1.33	0.750	42
Lower = Basic basalt..........	1.00	1.000	36

The "Rother Gneiss" corresponded to Bunsen's "normal trachytic" magma, and the augite-porphyry to the "normal pyroxenic" magma.

The primary divisions of Scheerer are obviously very nearly the same as Durocher's acid, hybrid, and basic groups. The types themselves seem to have been established under the control of a genetic theory, and contrary to the evidence afforded by the tables of rock analyses published by Roth three years before the appearance of Scheerer's proposition. The latter does not refer to the conclusions reached by Roth, which were so directly opposed to his own.

Ferdinand Zirkel, 1866.—Shortly after the works by Roth, von Cotta, and Scheerer there appeared (1866) a work which may be taken as well representing the stage of development of petrographic system in Germany at the beginning of what may be called the era of the microscope. This work is the *Lehrbuch der Petrographie*, by F. Zirkel, who was to be one of the master spirits of following decades.

This treatise was, and, indeed, still is, a mine of useful information to the student, and its contribution to the systematic science was of much influence. Zirkel's elementary scheme of classification is the following:

A. Original crystalline rocks ("Ursprüngliche krystallinsche").
I. Simple rocks ("Einfache Gesteine").
II. Composite rocks ("Gemengte Gesteine").
    1. Composite crystalline-granular and porphyritic rocks ("Gemengte krystallinisch-körnige und Porphyr-Gesteine").
    2. Composite crystalline-schistose rocks ("Gemengte krystallinisch-schieferige Gesteine").
B. Clastic rocks ("Klastische Gesteine").

This arrangement has elements drawn from various sources. In the grand division into original and clastic (secondary) Zirkel followed Naumann, but returned to von Leonhard for the criterion of the second order. In rejecting von Cotta's system, based on mode of origin, Zirkel remarked that this plan would be highly satisfactory were it not founded upon hypothetical considerations. He secured divisions closely corresponding to von Cotta's eruptive, sedimentary, and metamorphic classes by roundabout means.

In his arrangement of original simple rocks, Zirkel practically followed Naumann.

In the *Lehrbuch* igneous rocks were given the greatest attention. They were brought together in one group by applying three factors at once, as *composite crystalline-granular and porphyritic rocks*. In practice the noncrystalline or vitreous rocks were also included here. This inconsequent proceeding was necessary to bring the eruptive or igneous rocks together, a fact demonstrating that the chosen method of primary subdivision was logically incorrect. The first subdivision of this group was by relative age into the *Older* and *Younger* rocks, a distinction which Zirkel himself recognized was highly artificial.[1] He pointed out that rocks of certain characters had actually received different names, according to age, although the time factor had not been used in their systematic arrangement; and he chose to be logical in application of that factor, to agree with usage, rather than to eliminate the duplicate terms. Had he chosen the latter alternative it is safe to assert that much of the still existing confusion from unnecessary duplicate rock names might have been avoided.

In further systematic subdivision mineral composition and texture were used in ways which have been followed more or less closely by many petrographers to the present time. Following Roth and others it was first determined to consider all rocks of the groups in question as *feldspathic* or *non-feldspathic*. Feldspathic rocks were held to include all in which feldspars or feldspathoids were present in appreciable amount. By this course two very unequal divisions were created and the qualitative element of mineral composition was confirmed in its position of dominance over the quantitative, which has had such unfortunate influence upon systematic petrography to this time.

The plan of forming a great group of feldspathic rocks may have appeared to be desirable on account of the belief, long since shown to be erroneous, that four kinds of feldspar, namely, orthoclase, oligoclase, labradorite and anorthite, seldom occurred together, and therefore might be used to characterize four great series of rocks. The feldspathoids were used to define another large series.

---

[1] *Lehrbuch*, Vol. I, pp. 446, 447.

It appears that in this proposition to use qualitative mineral composition as a leading factor in classification, as in that to apply the age distinction, Zirkel merely gave definite expression to the growing usage of the time, which was practically found in other systems, though not so clearly avowed as a principle. The effect of his proposition to apply geological age and this qualitative element of mineral composition as leading factors in the systematic arrangement of the rocks we now term igneous was peculiarly unfortunate, because this invaluable work of reference was issued at the beginning of the era in which petrographers were to be so busily engaged in the microscopical study of rocks that they had no time for systematic work. In the flood of descriptive literature of the succeeding decade these propositions were adopted almost of necessity. The students from all lands who flocked at this time to Germany to study under Zirkel and other masters, carried the system back to their respective countries, giving it quickly a world-wide usage.

Ferdinand von Richthofen, 1868.—Shortly after the appearance of Zirkel's *Lehrbuch* a philosophical discussion of the classification of igneous rocks, as viewed from the geologist's standpoint, was published by the distinguished German traveler and geologist, Ferdinand von Richthofen. This essay was written and published during an extended visit in the United States, under the title "Principles of the Natural System of Volcanic Rocks."[1]

Von Richthofen calls systematic petrography "the most intricate branch of descriptive natural science." He characterizes the earlier systems as artificial, because based upon the idea "that classification should be made dependent on one certain principle previously assumed as the point of issue." The principles especially named as used in this way are, crystalline texture, lack of stratification, predominance of silicates, etc. To von Richthofen it appeared that the exact mineral composition of rocks as a basis for their classification had become possible after the investigations of Gustav Rose on the feldspars, and that by this means petrography had been brought out of a chaotic state. While acknowledging, therefore, the high value of mineral composition as a basis for classification of igneous rocks, von Richthofen considered that its exclusive application had grouped rocks geologically far separated, and distinguished rocks geologically closely connected, which seemed to him a fundamental error.

---

[1] *Memoirs presented to the California Academy of Sciences,* Vol. I, pp. 39–133, 1868.

The "natural system" of igneous rocks proposed by this author was based upon the Bunsen law of two fundamental magmas, and upon what he considered to be demonstrated facts of a broad correlation between developed texture and age of igneous masses, and of an order of succession of magmas in the history of the earth. By using "eruptive" as a collective term for all rocks under discussion, he implied the adoption of geological mode of origin as the first principle in classification. Von Richthofen remarked that Bunsen's law might have to be revised, "but no change of its principles may ever be expected, as an overwhelming amount of evidence has accumulated in support of its essential tenor." Texture is used by von Richthofen as the second principle in system to produce three classes of eruptive rocks: granite, porphyritic, and volcanic. He says that the conclusion appears to him to be justified "that the three great classes of eruptive rocks are geologically separated and represent three successive and distinct phases of the manifestation of subterranean agencies." The granites of the Sierra Nevada, with which he had personally become familiar, forced von Richthofen to admit that in some parts of the world the ancient granitic and porphyritic eras were succeeded by later eras of the same rocks, within the Mesozoic, but he believed that the volcanic era began with the Tertiary, both in Europe and America. The old lavas of the British Isles, known since the early decades of the century, were either disregarded or overlooked by him.

Mineral composition was regarded by von Richthofen as "essentially dependent on the chemical composition," and was used by him as "more articulate" than the latter, in the construction of his scheme. The outline of von Richthofen's systematic arrangement is as follows:

Eruptive Rocks:

- Class I. Granitic Rocks.
  - Orders: 1, Granite; 2, Syenite; 3, Diorite; 4, Diabase.
- Class II. Porphyritic Rocks.
  - Orders: 1, Felsitic Porphyry; 2, Porphyrite; 3, Melaphyr; 4, Augitic Porphyry.
- Class III. Volcanic Rocks.
  - Orders: 1, Rhyolite; 2, Trachyte; 3, Propylite; 4, Andesite; 5, Basalt.

The further mineralogical variation of rocks was expressed in families under each order.

In this system three principles were applied: (1) Mode of origin; (2) A supposed fact of correlation between age and texture; (3) Chemical composition as represented in mineral composition, and practically expressing the author's belief in the Bunsen law.

While von Richthofen's system was not followed in its details by petrographers, some space has been given to it here because of its influence upon many geologists, perhaps especially in the United States, and because it illustrates so clearly the perils of introducing genetic ideas into the systematic classification of igneous rocks, even when those ideas are believed to be established as laws.

It may be mentioned here that von Richthofen enunciated practically the same views in his *Führer für Forschungsreisende*, issued in 1886.

Cordier's system and its influence.—Turning now to France, before taking up the essays at classification made during the era of the microscope, it appears at first thought strange that for thirty years after Brongniart's classic work no important advance was made in the systematic classification of rocks in that country. And when a very significant advance was made, it appears not to have been recognized. The master spirit of French petrography during this period and until his death was P. L. A. Cordier. He was engaged until the end in carefully elaborating his system of classification, which was presented in lectures and applied to the great collection of the Museum of Natural History in Paris. Cordier does not seem to have published his classification himself, but it was made known by his associate, Charles d'Orbigny, in the *Dictionnaire universel d'histoire naturelle*, article "Roches," and others, Paris, 1842–1848; and in the volume *Description des roches*, etc., edited from the manuscript and lectures of Cordier, published in Paris, 1868, seven years after his death.[1]

The stagnation in systematic petrography in France during this period may be referred to two causes: First, the inherent weakness of Cordier's system; and, second, the traditional custom prevailing in France which gives to the recognized master in any branch of science a strongly dominant influence, which few are willing to openly oppose.

The weakness of Cordier's system came chiefly from the fact that it was, like that of Haüy, based too largely upon the convenient arrangement of cabinet specimens. Viewing rocks simply as aggregates of minerals, they were studied in detail, and their broad relationships were ignored, as belonging wholly to geology. In 1848, only two years before Naumann issued his philosophical analysis of petrography, and 33 years after Cordier published his own first scheme for the arrangement of volcanic rocks, his comprehensive system was announced by D'Orbigny, in the cited article of the *Dictionnaire universel*, etc., to have the following features:

Its fundamental idea was that the classification of rocks should be grouping of *species*, not a subdivision of the grand category of rocks. The species, based upon composition, was regarded as a nearly constant mixture of certain elements and as characterized by a certain structure. Species were supposed to be much more numerous than the unimportant transition types—"roches du passage."

---

[1] At an earlier date it was translated into German by Kleinschrod, in *Jahrbuch für Mineralogie*, 1831, p. 17.

The rock species was determined almost solely on mineralogical grounds. Geological origin and occurrence were used merely as appropriate elements in the description of the species —stating its *habitat*, so to speak.

Species were grouped in genera according to the state of aggregation, as explained below. Orders were based upon the power of the eye to distinguish the character of the rock. The most important of the still larger groups, the family, was formed in most cases upon the *predominant mineral present*, and the families were grouped upon an indefinite chemical basis, in four classes, namely:

Class 1. Earthy rocks (roches terreuses).

Class 2. Saline or acid non-metalliferous rocks (Roches salines ou acidifères non métalliques).

Class 3. Metalliferous rocks (Roches métallifères).

Class 4. Combustible non-metallic rocks (Roches combustibles non métalliques.

Predominance of one mineral constituent, the quantitative factor applied to form families, the most important of divisions aside from the species, was assumed to mean: (1) more than half where two constituents were concerned; (2) more than one-third where three constituents were present, and so on. In complex rocks it was naturally difficult of application and was almost impossible in aphanitic rocks. Moreover, it was not adhered to strictly, as pointed out by D'Orbigny in regard to basalt, which was referred to the pyroxenic family although feldspar might really predominate over pyroxene. As D'Orbigny naïvely remarks: "But it is this latter substance which gives its character to the rock" (Mais c'est cette dernière substance qui donne son caractère à la roche).

The elaborate system of Cordier may be illustrated by the following section, giving the subdivisions within the feldspathic family:

Class I. Earthy rocks (Roches terreuses).
First family, feldspathic rocks (Roches feldspathiques).

- 1. Order. Phaneromeric — of which the constituents are visible to the naked eye (Phanérogènes dont les éléments sont visible a l'œil nu).
  - 1. Genus. Aggregates (agrégées).
    Species: (1) harmophanite, (2) leptynite, (3) gneiss, (4) pegmatite, (5) granite, (6) syenite.
  - 2. Genus. Conglomerates (Conglomérées).
    Species: (1) feldspathic breccia, (2) feldspathic conglomerate, (3) feldspathic grit and sandstone.
  - 3. Genus. Unconsolidated sands, etc. (Meubles).
    Species: (1) Feldspathic sands and gravels (sables et graviers feldspathiques), (2) pebbles and débris of feldspathic rocks (galets et débris de roches feldspathiques).
- 2. Order. Aphanitic — wholly or partially (Adélogènes en tout ou en partie — dont le volume des parties est en totalité ou en partie invisible).

Other families of earthy rocks are named after pyroxene, amphibole, garnet, hypersthene, diallage, talc, mica, and quartz. An inconsequent element in the construction of the system, found in various places, is illustrated in the eleventh family, vitreous rocks, introducing a new factor while stating that the rocks in question are *feldspathic*.

The great majority of known igneous rocks are assigned by this system to the aphanitic (adélogène) orders of the various families, because their constitution is not wholly determinable by the naked eye.

The system of Cordier was the system of France for years after his death, in 1861, and was published in elaborate form by D'Orbigny in 1868.[1] In all essential particulars the system had remained unchanged. At the beginning of the chapter upon the principles of classification is the declaration: "The description of rocks requires in advance: (1) the formation of species; (2) their classification" (La description des roches exige avant tout: 1° l'institution des espèces; 2° leur classification). There is so little new in the construction of the system that no further analysis of it seems necessary.

---

[1] CHARLES D'ORBIGNY, *Description des Roches, ete.* Rédigé d'après la classification, les manuscrits inédits, et leçons publiques de P. L. A. Cordier. Paris, 1868.

No influence of Cordier's principles can be detected in modern systems for the classification of rocks. The importance of his system from the standpoint of this review lies in the retarding influence it exerted for several decades over the development of the science in the country where Brongniart had laid such logical foundations. But it seems to the writer that it was after all not so much the inherent weakness of Cordier's system as it was his domination over the thought of his countrymen, to a degree possible only in France, that retarded progress for so long. It is significant to recall that D'Orbigny's last presentation of the system appeared two years later than the *Lehrbuch* of Zirkel, but far more so to note, in confirmation of the opinion just expressed, that it was published eleven years after an important treatise on rocks, issued in Paris by a French geologist of renown, presenting a broad and logical view of petrographic system, which was not even referred to by D'Orbigny.

H. Coquand, 1858.—In 1858 there was published in Paris a work by H. Coquand, the title of which, translated, is as follows: *A Treatise on Rocks, Considered from the Point of View of Their Origin, Their Composition, Their Occurrence, and Their Use in Geology and Industry.* This book has over four hundred pages, and contains a classification of rocks very different from any earlier or contemporary scheme, but it has received very little recognition in spite of its merits. Coquand was professor of mineralogy and geology in the College of Besançon. Possibly he did not belong to the distinguished coterie of Parisian geologists, and in that case the fact that he should come out with a system full of originality, strongly opposing that of Cordier, who was still alive, may have been regarded by his contemporaries as such a flagrant violation of unwritten law that the only course open to them was to ignore his proposed scheme of classification.

The title of Coquand's treatise shows at once how completely he had broken away from the traditions of his countrymen. His classification has little in common with other French systems, and, if not wholly original, one must suspect the dominant influence of Naumann's views. Its main outlines are as follows:

Three families of rocks are recognized:

- I. Igneous rocks.
- II. Aqueous rocks.
- III. Metamorphic rocks.

Igneous rocks are divided into three groups:

1. Granitic (in the sense of granular).
2. Porphyritic.
3. Volcanic.

Aqueous rocks into three groups:

1. Chemical deposits.
2. Mechanical deposits.
3. Carbonaceous rocks, of vegetable origin.

Metamorphic rocks into three groups:

1. Crystalline schists.
2. Those of chemical origin.
3. Those of mechanical origin.

It will be seen that this system is in its outline wonderfully like many of recent years in its logical use of factors in construction, and in the order of their application. In further subdivision, finally producing species, Coquand was less fortunate, being governed still by the mineralogical idea too closely. Probably he was much less fitted for the descriptive task than Cordier, who doubtless surpassed him in intimate knowledge of the detailed characters of rocks as cabinet specimens; but he certainly possessed a logical mind, and grasped far better than his contemporaries the relations of petrography to geology.

Archibald Geikie, 1872.—Turning to the literature of other countries during this period, it is evident that systematic petrography was developed as a science almost wholly through the labors of workers in Germany and France. Prior to the microscopical era, soon to be considered, practically no special students of this subject appeared in either Great Britain, America, or in other countries. Aside from the discussions of geologists, like De la Beche, already mentioned, there was in Great Britain no important contribution after the time of Macculloch. The conditions in that country up to 1870 may be summarized by the statements of Archibald Geikie, in 1872, in the *Students' Manual of Geology*. He there says: "There is as yet no good English treatise on petrography, or the classification and description of rocks." In this work all rocks are first classified "under the four great heads of igneous, aqueous, aerial, and metamorphic, according to the nature of the agencies by which they have been brought into their present state and position." "Igneous rocks without exception are composed of minerals which are silicates. These minerals may be said to belong to two great classes: silicates of magnesia and silicates of alumina," each combined with other bases. "The felspars are the bases of all truly igneous rocks, those in which no felspar or mineral of that type is present being very few and unimportant, even if they exist at all." Here we see the proposition made by Zirkel stated in extravagantly positive terms.

Igneous rocks are divided into volcanic, trappean, and granitic, with crystalline and fragmental subdivisions under the first two. The trappean class is vague and "of convenience only." In the volcanic class the law of Bunsen is practically recognized and two groups established: "the trachytes, or felspathic or acidic group," and "the dolerites, or pyroxenic or basic group." Similar groups are formed under the trappean class. The granitic class embraces only granite and syenite.

WHITMAN CROSS.

(To be continued.)